TO INCREASE THE YIELD OF FOOD

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It is better always that fifty bushels of grain grow on one acre than that they grow on ten, even at equal cost. As agriculture is more intensive, so may civilization be more intense. Economically, socially, and probably physiologically, the area condensation of food production is as important as any problem which confronts the race—quite as important in twentieth century America as it was in Egypt thirty centuries ago.

Dimly recognized as this basic principle of food-supply and development may have been at all times, yet it is doubtless due to this fact that the first important application of scientific research to agriculture was in the investigation of the soil. Urged no doubt by the obviousness with which the growth of the useful plants depends upon fertility and good conditions of soil, early investigators directed their efforts largely to problems in this field. One may recall the basic investigations of de Candolle in plant nutrition, of Wollney in soil physics, and of Hellriegel in soil bacteriology; investigations which are still among the classics of applied science. For some reason this early primacy of soil investigation has not continued. The energies and resources of agricultural science have come to be applied less to problems of the soil and more to problems of plant improvement, the control of insect and fungus enemies, the creation of new agricultural products, or the mere betterment of cultural technique.

There has been no decrease in the number or urgency of the problems which raise themselves in the advance of modern agriculture. The reverse is true. The specializations in crops, the refinements in products, and the increasing pressure of land valuations have raised a host of difficulties in modern agriculture.

Serious as the implied needs may be, yet the rapid advance of the sciences of physics, chemistry, and experimental biology has not only increased greatly the available points of attack on evil problems, but has provided many new methods for the necessary experimentation. Knowledge does not apply itself, however. Long and costly intervals may intervene between the dawn of a discovery and its actual utilization. Agriculture now finds itself moving slowly with respect to many of the principles of science that may affect its progress most profoundly. An inquiry as to the most pressing problem would doubtless be answered differently by scientists, in a manner determined by viewpoint and experience. Should a census of opinion be obtained from those whose work engages with agriculture, however, there is little doubt that a general agreement would be found as to the necessity for an intensive application of creative intelligence and experimental skill to the study of the general and fundamental properties of the soil.

Simple and didactic as it may seem, a primary requirement to any material progress in soil-science is the formulation of some simple way of expressing and recording the physical nature of the soil. If we are to make progress in the art of using soils in growing plants, we must not only have a clear conception of the physical nature of soils, but we must be able to understand one another in discussing the subject.

The substratum within which proceed the innumerable chemical and biological reactions of the soil is a loosely piled mass of mineral particles of different sizes, shapes and arrangement. The nature of these mineral particles determines the physical character of a given soil; for instance, as to whether it is sand, clay or loam. On the basis of present knowledge it is impossible to define precisely either these terms or the physical character to which they refer. Soils are now classified physically according to what is called the "mechanical analysis," which is a statement of the numbers (or total weights) of soil particles falling within each of certain specified classes between arbitrary limits of size. Thus the "sand" class is limited by particle diameters of .5 millimeter and .3 millimeter; the clay class includes all particles smaller than .01 millimeter, etc. The mechanical analysis states the percentages by weight of sand, "clay," and other particles as thus defined, which are present in the

given soil. There are many disadvantages in this system, but the most serious is that the results are not commensurable. A statement of a given mechanical analysis contains as many terms as the classes of particles which have been agreed upon (never less than seven) and will not reduce to a single simple number. For instance, one cannot range soils in the order of their mechanical analysis, as trees might be classed according to height or casks according to cubic contents. Consequently, to think of the physical condition of soils is a mental process of some complexity and difficulty. Some system of determining and expressing this very important soil characteristic in simple and comparable terms would immensely facilitate soil investigation by providing means for adequate and precise comparisons between the physical character of different soils, especially when varied cultural capacities were being studied or compared. Indications are available of at least two ways in which such a simple soil constant might be obtained. First is the water-holding power of a soil when a sample is whirled in the centrifuge at a given speed. Under these conditions a definite amount of water is retained by the soil against the centrifugal force, and the amount so retained, if expressed as a percentage of the soil, appears to be related closely to the physical character of the soil.[1] The second suggestion comes from the discovery by Cameron and Gallagher [2] of what they call the "critical moisture content" of a soil. This is a certain more or less definite percentage of water in the soil at which all of the physical properties such as permeability, resistance to root penetration, etc., appear to be either at a maximum or at a minimum. Speaking mathematically, the physical properties "invert" at this particular percentage of water. The actual value of this percentage, also, appears to depend closely upon the physical nature of the soil. Neither the water retention as measured against centrifugal force, nor the critical moisture content of Cameron and Gallagher, has been investigated sufficiently to make sure of its practical value, but both would repay completer study.

A second inquiry of no less importance is the study of the diffusion of dissolved substances along thin liquid films. In ordinary soils, which are neither extremely dry nor extremely wet, the water of the soil is present as a system

[1] Briggs and McLean, United States Bureau of Soils, Bulletin 45, 1907

[2] United States Bureau of Soils, Bulletin 50, 1907.

of thin films enveloping the mineral grains. Where two mineral grains touch or come close together, the water films which surround them merge and the soil-water thus forms a continuous network of liquid films and filaments. If the solid particles of the soil could be imagined as removed, the water system would resemble a very complex and irregular honeycomb. The mineral salts and other substances which are the food materials of plants must reach the plant roots in solution, and in order to do so these substances must dissolve in the soil water and diffuse for longer or shorter distances through the water-film system which has just been described. It is known that because of forces analogous to the surface tension of liquids, the diffusion of dissolved substances through thin films obeys physical laws which differ from the laws of diffusion through ordinary masses of water. The precise nature of these differences and of the laws which do operate in thin films are unknown. This is a matter so fundamental to the food supply of plants that a more complete understanding of it is vitally necessary to any serious advance in knowledge of soils.

These two problems involve what might be called physical conditions. In the chemical field perhaps the most important problem is that of availability to the plant of food materials contained in certain minerals of the soil. For instance, potassium is one of the elements for plant growth. Normal soils contain large quantities of potassium in the form of feldspar and other potassium silicates. For some reason, however, the potassium in feldspar appears to be unavailable to the plant or to become available only partially and slowly. Thus it is found that the addition to soils of potassium in the form of commercial fertilizers is beneficial and sometimes necessary, even when the soil already contains, in feldspar form, many times the quantity of potassium added in the fertilizer. Analyses of 1831 American soils have been made by the United States Bureau of Soils according to a method which extracts only the more soluble fraction of the potassium.[1] Even though not all of the potassium was determined, these analyses showed potassium contents up to 2.0 per cent. and averaged 0.3 per cent. This average corresponds to about eight tons of potassium chloride per acre of soil taken to a depth of one foot. The usual application of

[1] United States Bureau of Soils, Bulletin 57, pp. 60-94, 1909.

potassium chloride in commercial fertilizers does not exceed one-fourth ton per acre, but is sufficient to increase growth. The cause of this anomaly is entirely unknown.

An investigation resulting in the discovery of some way of unlocking the unavailable soil potash would have a value the magnitude of which is just now unusually apparent. The interruption by the War of the supplies of potassium formerly received from Germany has already caused notable damage to American agriculture, and is the occasion of increasing concern to thoughtful economists. Phosphorus is frequently present in the soil, but is unavailable, in much the same way as is potassium, but its practical importance does not happen to have been emphasized so sharply by commercial deficiency.

In this same field of the nutritive characteristics of the soil there is another problem of great scientific interest, which may prove to be of even more practical importance. This is the effect on plants of certain minor constituents of the soil, the presence and effects of which have been almost entirely overlooked. For instance, boron, arsenic, copper, lead and many other elements have been found to be present in soils very generally, perhaps universally, but in minute proportions. Laboratory investigations in plant physiology have shown that very small quantities of some of these same elements have significant effects on plants; sometimes toxic, sometimes stimulating. For instance, Agulhon [1] found wheat plants so stimulated by .0025 per cent. of boric acid in the soil that the dry weight was increased 7.5 per cent. Somewhat greater applications of boric acid to radishes produced an increase of 61 per cent. in the fresh weight and 9.6 per cent. in the dry weight. Field experiments in Japan with the application of manganese sulphate to rice gave an increase of 37 per cent. in the harvest from the use of seventy pounds of the manganese salt per acre.[2] Practical applications of these phenomena are not directly in sight, but the systematic investigation of both sides of the problem (soil and plant) might lead to generalizations concerning the functions of these minor elements in the soil, and thus suggest possibilities of useful employment. For instance, the development of an agricultural value for arsenic would find

[1] *Recherches sur la presence et le rôle du bore chez les végétaux*, Thesis, University of Paris, 1910.

[2] M. Nagaoka, Bulletin College of Agriculture Tokyo, Vol. 6, pp. 135-136, 1904.

an immense supply of arsenic compounds coming as by-products in copper smelting now considered worthless. The secondary effect of the use of this material might be even more important than the first by facilitating the production of a metal of constantly increasing importance.

Turning to the organic materials and reactions of the soil, it is interesting to recall that the earlier students of soil chemistry regarded the soil organic matter, or humus, as without significant effect on productivity. This is now known to be a serious error. Experiment has shown that certain organic chemical compounds which are normally or occasionally present in humus may produce startlingly great effects on plant growth. Thus Schreiner and his associates [3] have isolated from certain infertile soils an organic compound, dihydroxystearic acid, which is found to be harmful to plants when present in the culture solution in concentrations as low as .001 per cent. Several other harmful substances have been isolated and others have been found to be beneficial. Many of these substances need be present only in minute traces for their effects to be perceptible and important. Knowledge of the chemical nature of humus is very meagre, and it is unknown whether its effects on plants are always exerted directly or may arise through influences on soil bacteria. In either case a precise knowledge of the chemical constitution of humus would probably lead not only to an understanding of the observed effects, but to means of controlling them in the interest of agriculture. Such understanding of humus would enable, also, a better analysis and more complete control of the well-known physical effects of humus material on soil texture and on the retention and movement of water in the soil which is so important in dry-land agriculture. Present knowledge of these matters is entirely empirical.

The practical importance of soil bacteria, like the significance of the humus substances, is just beginning to be recognized. It is now known that normal soils contain many kinds of bacteria, as well as numerous protozoa, nematodes, fungi and other lower organisms, both animal and vegetable. Many of these organisms are beneficial to the useful plants; probably some are essential. Others are seriously harmful. Still others are without direct effect, but are secondarily influential through the encouragement or destruction of the

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[3] See especially United States Bureau of Soils, Bulletin 70, 1910.

organisms which are directly effectual. The micro-organism complex of the soil is a veritable little world with the most diverse reactions and equilibria, all of which are of the utmost importance to agriculture. The practical possibilities of influencing this complex microflora and fauna appear to be great. Not only are many chemical substances known to be influential in stimulating or suppressing specific groups of organisms, but the selection and development of especially active or resistent varieties of desired bacteria is just as possible as is the analogous development of desirable varieties of the higher plants. The great improvement of the fermentation yeast which has been accomplished by the brewers, vintners, and bread-makers is a case in point. If, for instance, the well-known group of soil bacteria which have the power of producing nitrates by the fixation of atmospheric nitrogen could be improved to an extent comparable with that achieved in the case of yeast, it would be possible to fix in the soil itself and at almost no cost sufficient nitrogen for the needs of agriculture. The manufacture of nitrates from the air by the electrical methods now so strongly advocated would be necessary, if at all, only for the purpose of industrial chemistry. It is probable, indeed, that this chemical demand could be met for many years by nitrogen compounds from the by-product coke ovens. It is not at all improbable that the permanent solution of the nitrogen problem will be found in the soil bacteria and not in electrochemistry.

The fact that almost any of the measures suggested in the preceding paragraphs would have a possible importance beyond the attainment of their direct purpose in agriculture, and in other activities, is so obvious as to need no further discussion.

The methods of attacking the main problem of the soil must be those of physics, chemistry, and experimental biology. Nothing is to be gained by empirical field experimentation. There must be focused on the researches the efforts of the best specialists in the experimental sciences and the entire technical and intellectual resources of all of these sciences. Such an expenditure of energy would be well warranted on the purely material ground of increased production, but its justification is far surer and its importance far wider than by virtue of mere increase of food.

The events of the last three years have made it apparent

beyond all possibility of contradiction that the welfare of the race as a whole depends in a large measure upon the fullest and widest development of all the resources of the separate regions inhabited by various peoples or nations. Basic facts support the generalization that communities or races are most successful according to the degree in which they are self-maintenant and self-contained. Dreams of denationalization and of socialization of the world cannot annul or evade this well recognized biological law. The population of a country may well devote the major part of its energy to industries centered on the raw materials locally most abundant or readily procurable. Any neglect of lesser needs or possibilities, or any failure to develop the natural resources of a region, constitutes a defect which may become a danger.

The soil is one of the most important resources of all countries, and national existence, racial security, and international stability must in the end rest largely upon the extent to which it is developed in every country. Researches upon its properties and capacities as accurate, detailed, and exhaustive as those devoted to the metals, to textiles, and to other resources, would have even more important benefits than those accruing from the results of the splendid technological studies upon these materials.

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